Occupational Exposure to Environmental Tobacco Smoke

S. Katharine Hammond, PhD; Glorian Sorensen, PhD, MPH; Richard Youngstrom, MS, CIH, CSP; Judith K. Ockene, PhD

Objectives.—To measure occupational exposures to environmental tobacco smoke in diverse settings, including offices and production areas, and to evaluate the effectiveness of policies that restrict or ban smoking in the workplace.

Design.—Survey. The average weekly concentration of environmental tobacco smoke was measured with passive monitors that sample nicotine. Approximately 25 samplers were placed in each worksite for 1 week.

Setting.—Twenty-five Massachusetts worksites, including fire stations, newspaper publishers, textile dyeing plants, and manufacturers of valves, fiberoptics, flight instruments, batteries, adhesives, semiconductor equipment, filters, and tools and dies. Samples were collected in offices and production areas.

Main Outcome Measures.—The distribution of nicotine concentrations in various work settings as a function of company smoking policy. These data were interpreted with three approaches: comparing measured concentrations with a published risk assessment; comparing occupational exposures with home exposures; and evaluating the "cigarette equivalents" to which workers were exposed.

Results.—Worksite smoking policy had a major effect on the nicotine concentrations, which fell from a median of 8.6 $\mu g/m^3$ in the open offices at worksites that allowed smoking to 1.3 $\mu g/m^3$ in sites that restricted smoking, and to 0.3 $\mu g/m^3$ in worksites that banned smoking. The nonoffice workspaces were affected similarly, with median concentrations of 2.3, 0.7, and 0.2 $\mu g/m^3$ at worksites that allowed, restricted, and banned smoking, respectively.

Conclusion.—All three evaluation methods indicated that occupational exposure to environmental tobacco smoke presents a substantial risk to workers in the absence of a policy restricting or banning smoking.

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SEVERAL REVIEWS of the literature during the past decade have documented the adverse health effects of exposure to environmental tobacco smoke (ETS).[1-5] Various studies have estimated that, each year in the United States, ETS causes the deaths of approximately 3000 nonsmokers from lung cancer[5] and may cause another 30 000 to 50 000 heart disease fatalities.[6,7] Furthermore, ETS causes respiratory diseases in young children[5] and may contribute to increased risk in adults as well. Because ETS is so ubiquitous and has so many serious adverse health effects, it is considered the single most important indoor air contaminant.

From the Departments of Family and Community Medicine (Dr Hammond) and of Behavioral Medicine (Drs Sorensen and Ockene and Mr Youngstrom), University of Massachusetts Medical School, Worcester. Dr Hammond is now with the Environmental Health Sciences Division, School of Public Health, University of California, Berkeley. Dr Sorensen is now with the Division of Cancer Epidemiology and Control, Dana-Farber Cancer Institute, Boston, Mass, and the Department of Health and Social Behavior, Harvard School of Public Health, Boston. Mr Youngstrom is now with the Division of Cancer Epidemiology and Control, Dana-Farber Cancer Institute.

Reprint requests to Environmental Health Sciences Division, School of Public Health, University of California, Berkeley, CA 94720-7360 (Dr Hammond).

People are exposed to ETS in their homes, at work, and in public places. Most epidemiological studies of adverse health effects have focused on home exposures under the assumption that a smoking spouse or parent exposes other household members and more time is spent in the home than at any other location. Regulatory efforts to limit exposure have focused on exposures in public places, such as governmental buildings, restaurants, and commercial aircraft. Occupational exposures have been the least studied.

One major question is whether the exposures in the workplace are comparable in concentration with those in the home, where epidemiological evidence has demonstrated the adverse effects of ETS. The workplace is second only to the home as a location in which adults spend time.

Approximately 110 million Americans work outside the home and may be exposed to ETS at work. This exposure is involuntary. For an individual who lives with nonsmokers, the workplace is often the major source of ETS exposure,[3] which may continue for 40 to 45 hours per week during a 45-year working lifetime. The Occupational Safety and Health Act states the employer has a general duty "to furnish to each of his employees ... a place of employment which is free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees" (section 5[a][1]).[9] Workplaces that allow smoking may not be meeting this duty.

In 1992, 59% of worksites that employed more than 50 workers had a formal policy that either banned smoking or restricted smoking to ventilated areas,[10] a substantial increase from 1985, when only 27% of worksites reported such policies. The increasing adoption of worksite nonsmoking policies is a reflection of legislative changes as well as increasing concern about liability and the health effects of ETS. According to the 1989 surgeon general's report,[11] 31 states required smoking restrictions in public worksites and 13 required them in private worksites as well.

Nonsmoking policies can influence the air quality in companies. After New England Telephone implemented a smoking policy, self-reported exposure to smoke in areas where smoking was prohibited decreased; however, workers reported that air quality either worsened or stayed the same in places where smoking was allowed.[12] After a policy that restricted smoking to a few designated areas was implemented in a Canadian worksite, employees' reports of being bothered by smoke decreased except in areas where smoking was permitted, such as in cafeterias.[13] A study of 710 worksites with nonsmoking policies from 11 communities across North America found that compliance was highest in worksites with more restrictive policies.[14]

This investigation was undertaken to study the levels of ETS to which nonsmokers are exposed while on the job. Although most studies of occupational exposure to ETS have examined the office environment, this study includes a variety of nonoffice workers, eg, production workers and firefighters, at 25 diverse worksites. These measurements were made as part of the WellWorks project,[15] a worksite cancer prevention study, and employees were potentially exposed to other carcinogens or suspected carcinogens. A second aim of this investigation was to examine the efficacy of workplace smoking polices in reducing occupational exposure to ETS.

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METHODS

Worksites participating in this study were part of the WellWorks project, one of four intervention research centers participating in the Working Well Cooperative Agreement, a randomized worksite intervention trial funded by the National Cancer Institute (participating centers are listed in the acknowledgment at the end of this article). Worksites from central and eastern Massachusetts were recruited to the WellWorks study[15] if they met the following eligibility criteria: employed 200 to 2500 employees; had less than 20% turnover per year; had less than 20% of full-time employees who did not read or write English; and used a known or suspected occupational carcinogen. All 24 participating worksites agreed to be randomly assigned to either an intervention (health promotion and prevention) or a comparison condition; to permit surveys of employees and company representatives; and to allow measurements of ETS levels. At the worksite's request, a 25th worksite, a local union office where 15 people worked, was surveyed concurrently by the same sampling protocols, and the results are included in this report. These surveys were conducted from 1991 to 1992. The 25 worksites that participated in the ETS survey had a broad range of business functions: newspaper publishing, firefighting, clothing imprinting, textile dyeing, union organizing, and manufacturing of flight instruments, aerospace technology, knives and tools, tools and dies, batteries, synthetic rubber products, semiconductor equipment, valves, metal parts, fiberoptics, adhesives, process controllers, blood processing equipment, and filters.

The average weekly concentration of ETS was determined by a passive monitor that samples nicotine; a filter treated with sodium bisulfate is held in a modified 4-cm-diameter polystyrene cassette, a membrane filter serves as a windscreen, and nicotine passively diffuses to the treated filter, where it is trapped. The effective sampling rate is 24 mL/min. The collected nicotine is analyzed by gas chromatography with nitrogen selective detection; details are presented elsewhere.[16,17] The limit of detection was 0.01 μg per sample, or 0.1 μg/m³ for 45 hours.

Approximately 15 to 25 samplers were placed in each worksite and left in place for 1 week. The monitors were placed at work areas in the offices and the nonoffice (shop) areas to determine an overall measure of ETS exposure for each worksite. In large worksites with multiple buildings, samplers were placed in one building that had representative work areas (office and shop). In offices and shop locations where employees worked in fixed locations, the smoking status of the occupant was assigned to the sample. Since most shop employees did not work in fixed locations, samples were placed around the shop floor approximately 1.5 to 2 m high; unless a smoker routinely worked within 1 m of the sampler, the sampler was assumed to reflect the exposure of nonsmokers. A description and the name of a company contact person were posted with each sampler.

Each monitor sampled air continuously for 1 week, so that daily variations were not evaluated but rather the average nicotine concentrations during the week for each sampler. Smoking was assumed to be taking place for 9 hours a day on each workday (8 hours of work plus 30 minutes to 1 hour of lunch or break time), except at the fire stations, where occupancy was presumed to continue for two thirds of the day, or 16 hours per day, 7 days a week. The concentrations of nicotine reported herein for each monitor were calculated to reflect the average exposure during those periods.

Information on company smoking policies was collected at baseline by the Organizational Information Questionnaire administered to the personnel directors at all worksites. Companies were classified into one of three categories based on their smoking policy: (1) smoking allowed throughout the worksite, except restrictions for safety reasons (11 worksites); (2) smoking restricted to designated areas only (eight worksites); and (3) smoking banned throughout the worksite (six worksites).

Work areas were classified as "closed office" (relatively small rooms with one or two occupants); "open office" (larger rooms, with or without partitions, in which many people worked); or "nonoffice" or "shop" (other work areas, including production, shipping, laboratories, and fire stations). Additional areas sampled included corridors, cafeterias, and other break areas. Unless one of the latter two areas had designated smoking and nonsmoking sections, all samples were assumed to represent possible exposure to nonsmokers.

RESULTS

These analyses focus on the 467 samples collected in the work (359 samples) and break (108 samples) areas of nonsmokers. The samples collected from the work areas of nonsmokers at 25 Massachusetts worksites were categorized into closed offices (13 samples), open offices (125 samples), and nonoffice, or shop, areas (221 samples).

Office Exposure

Samples were collected from the closed offices of 11 nonsmokers at worksites where smoking was allowed. The median nicotine concentration was 9.1 μg/m³ (range, <0.1 to 22 μg/m³; mean, 8.3 μg/m³). Only one sample each was collected in closed offices of worksites that restricted or banned smoking, and the levels were 0.6 and less than 0.1 μg/m³, respectively.

The weekly nicotine concentration measured at nonsmokers' desks in open offices (125 samples) varied by three orders of magnitude, from less than 0.1 μg/m³ to more than 40 μg/m³ (five samples). The distributions of these values varied dramatically with smoking policy at the worksite (Figure 1). For example, the median value dropped from 8.6 μg/m³ in companies that allowed smoking to 1.3 μg/m³ in those that restricted smoking and 0.3 μg/m³ in those that banned smoking (averages were 14, 3.4, and 0.7 μg/m³, respectively). The 90th percentile value in open offices at companies that allowed smoking was 34 μg/m³, averaged over the workweek, but was reduced to 9 μg/m³ in companies that restricted smoking and 1.7 μg/m³ in companies that banned smoking. Conversely, 24 (83%) of 29 samples collected at nonsmoking office workers' desks in companies that banned smoking were less than 1 μg/m³, while only 16 (46%) of 35 samples from companies with restrictive policies and only eight (13%) of 61 samples from companies that allowed smoking had such low exposures. Of the 29 samples collected at office workers' desks in companies with smoking bans, 12 (41%) showed nicotine concentrations less than 0.1 μg/m³.

Nonoffice (Shop) Exposure

The weekly nicotine concentrations measured in nonsmokers' work areas in the production areas and fire stations (221 samples) ranged from less than 0.1 μg/m³ to more than 20 μg/m³ (four samples). The distributions of these concentrations was also highly dependent on the worksite smoking policies (Figure 2). The median values were 2.3, 0.7, and 0.2 μg/m³ for worksites that allowed smoking, restricted smoking, and banned smoking, respectively, and the corresponding means were 4.4, 2.2 and 0.2 μg/m³. The 90th percentile levels in these companies were 7.2, 4.0, and 0.6 μg/m³, respectively. Nearly all (51 [96%]) of the 53 samples collected at companies that banned smoking had nicotine levels less than 1 μg/m³, while only 25 (22%) of the 114 samples from worksites that allowed smoking were this low (two thirds of these low samples were from areas where smoking was prohibited for safety reasons); 34 (63%) of the 54 samples from companies that restricted smoking were less than 1 μg/m³, and more than a quarter of the samples had nicotine concentrations that were less than detectable (<0.1 μg/m³), as did 23

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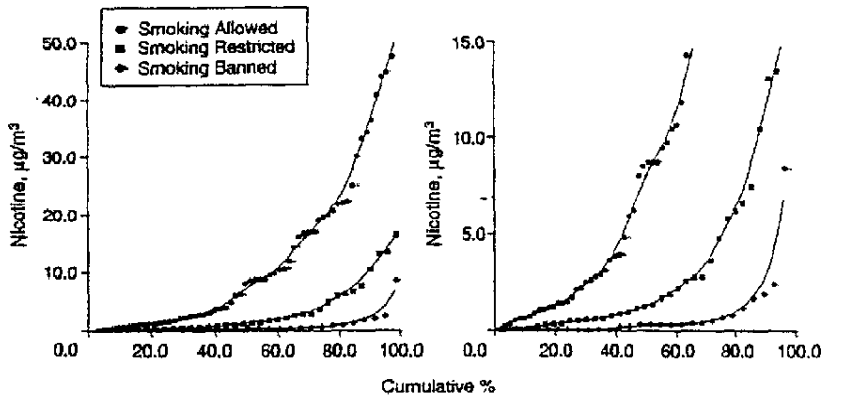

Figure 1.—Left, Cumulative frequency distributions of weekly average nicotine concentrations at the desks of nonsmoking workers in open offices measured at 25 worksites. Median (50th percentile) nicotine concentrations were 8.6, 1.3, and 0.3 µg/m³ at worksites that allowed, restricted, or banned smoking, respectively. Right, Nicotine concentrations at the desks of nonsmoking office workers, with detail provided at concentrations less than 15 µg/m³.

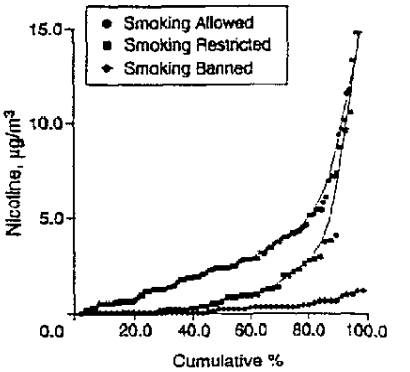

Figure 2.—Cumulative frequency distributions of weekly average nicotine concentrations in nonsmokers' work areas in shops and other nonoffice settings. Note that 10% of the samples had nicotine levels of more than 7.2, 4.0, and 0.6 µg/m³ at worksites that allowed, restricted, and banned smoking, respectively.

(43%) of the 53 samples from companies that banned smoking.

Break and Cafeteria Areas

Samples were collected in the cafeteria (57 samples) and break areas (51 samples), which are typically occupied for only a part of each work day. However, concentrations were calculated as an average over the full workweek; therefore, these concentrations are an underestimate of the actual concentrations during meal and break times, when these areas are normally occupied.

At companies that banned smoking, all nine of the samples collected in the cafeteria had nicotine levels less than 1 µg/m³. By contrast, this level was exceeded by all 15 of the samples at companies that allowed smoking and by 19 (86%) of 22 samples from those companies that restricted smoking; two thirds of these samples averaged more than 5 µg/m³.

Half of the 20 samples in the break areas from worksites that restricted smoking had nicotine concentrations greater than 5 µg/m³, while only four (20%) of the 20 samples from companies that allowed smoking were as high. The proximity of break areas to designated smoking areas may explain this result. More than 17 (85%) of the 20 break area samples from companies that allowed smoking had concentrations greater than 1 µg/m³.

COMMENT

This is the first large study known to us that reports the results of occupational exposure to ETS in multiple worksites and includes both office and manufacturing areas. These results indicate a strong correspondence between nonsmokers' ETS exposures and workplace smoking policies.

Although ETS samples were collected at smokers' and nonsmokers' workstations, this article focuses on those that represent nonsmokers' occupational exposures to ETS. The ETS exposures found in this study are similar to those reported in other studies that used active sampling for nicotine during a workshift to measure occupational exposure.[13-21] Muramatsu et al[18] measured nicotine concentrations in offices that averaged 20 µg/m³, in a laboratory that averaged about 6 µg/m³, and on airplanes that averaged 15 µg/m³. A median of 4 µg/m³ was reported for 16 personal measurements of flight attendants in 1988.[19] Coultas et al[20] measured the nicotine exposures of 15 nonsmokers during their workshifts in 1986 to 1987 and found median concentrations of 10 µg/m³ for five hospital workers, 7.2 µg/m³ for five office workers, 9 µg/m³ for two barbers, 7 µg/m³ for a maintenance worker, and 45 µg/m³ for a restaurant worker. Large variations were found in ETS exposures among nonsmoking railroad workers: 33 samples of office workers had a median nicotine concentration of 7 µg/m³, close to the median of 8 µg/m³ found in the present study at workplaces that allowed smoking, and the 25th and 75th percentiles of the railroad office workers' exposures were 2 and 12 µg/m³, respectively; 136 personal samples taken from those who worked outdoors or in a large repair shop indicated much lower ETS exposures, with the 75th percentile being a nicotine concentration of 0.5 µg/m³.[21]

Interpreting Exposures to ETS

Three approaches are used to place in perspective the occupational ETS exposures reported herein: (1) comparing the levels of occupational ETS exposures with a risk assessment reported in the literature; (2) comparing occupational ETS exposures with those in homes; and (3) evaluating the number of "cigarette equivalents" to which workers may be exposed.

Occupational Exposures Based on Risk Assessment.—Repace and Lowrey[22] evaluated the risk of ETS exposure in the workplace and estimated that workplace nicotine exposure of 2.3 µg/m³ for 40 years presents a lung cancer risk of three in 10 000, a "de manifestis" risk, ie, "a risk of obvious or evident concern," or risks so high that the US regulatory agencies have almost always acted to reduce them.[23] The Occupational Safety and Health Administration often considers action based on a "significant risk level" of one in 1000 and assumes 45 years of working life; the significant risk would thus occur at exposures to nicotine at or above 6.8 µg/m³. Figures 1 and 2 demonstrate that a substantial proportion of the nonsmoking workers at companies that allowed smoking were exposed above both levels. Of the 114 shop workstations sampled, 12% were above 6.8 µg/m³, and half were above 2.3 µg/m³, the de manifestis risk level. Offices at worksites that allowed smoking exposed an even higher percentage of workers to high levels of ETS: two thirds of the 61 samples were above the de manifestis level, and more than half of the samples from the offices surveyed were well above the significant risk level (Figures 1 and 2).

Clearly, banning smoking drastically reduced ETS exposures: none of the 82 work areas measured at the six worksites in which smoking was banned exceeded the significant risk level, and only two samples were above the de manifestis level. Those eight sites that restricted smoking had intermediate results, with

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10 (11%) of the 89 work areas being above the significant risk level and 25 (28%) being above the de manifestis level. Note that this risk assessment is based only on lung cancer. Although ETS-associated heart disease affects far more people than lung cancer does, quantitative risk assessment has not yet been performed.

Comparison of Occupational Exposure With Home Exposures.—Exposures to ETS are highly variable. In the home, workplace, or any other environment, the concentrations of nicotine may range from less than detectable to several orders of magnitude higher. With such variable data, averages can be misleading, and a more complete presentation of the data is needed. The box plots of several studies in Figure 3 show the 25th, 50th (median), and 75th percentiles of ETS exposure (enclosed in the box) as well as the maximum and minimum exposure levels (the range is indicated by the lines).

Figure 3 compares the occupational exposures to ETS measured at worksites where smoking was allowed with personal and home exposures. The first two box plots compare the personal exposures of nonsmokers married to smokers with those of nonsmokers not married to smokers,[24,25] the two groups whose risks for lung cancer and heart disease have been compared in most epidemiological studies of ETS. Although those married to smokers had higher exposures, there is clearly an overlap in distributions of exposures with those married to nonsmokers. The next two box plots show the levels of ETS in smokers' homes as measured by personal sampling on 22 children and area sampling in their homes.[26] The last two box plots present the results of the present investigation of the occupational exposures to ETS at companies that allowed smoking. As Figure 3 illustrates, the ETS exposures in workplaces that allow smoking is comparable with, and often greater than, the ETS exposures in smokers' homes as well as the personal exposures of nonsmokers married to smokers, who have been shown to be at increased risk for lung cancer and heart disease compared with *nonsmokers* married to nonsmokers.[1,5,6,27]

Cigarette Equivalents.—Researchers and advertisers have often tried to interpret measurements of nicotine exposure by converting these to "cigarette equivalents"[18,23] (RJ Reynolds advertisement, *New York Times*. May 23, 1994: A11). Such a calculation yields the number of cigarettes one would have to smoke to receive the same amount of nicotine as breathing the air in the given environment for a particular period. However, the ratio of sidestream to *mainstream* emissions is highly variable among these compounds. Nicotine serves as a marker compound for ETS,[29] but nicotine is not usually the compound of ultimate interest for cancer. Were "cigarette equivalents" calculated on the basis of the carcinogens in ETS, rather than nicotine, the cigarette equivalents would be much higher. This seeming anomaly results from the differences between mainstream and sidestream smoke.

Although the same toxic compounds are present in mainstream smoke (which the smoker inhales) as in sidestream smoke (which comes off the tip of a smoldering cigarette), they are emitted in different amounts because of the differing combustion conditions. Mainstream smoke is formed at a higher temperature, while much less oxygen is present when sidestream smoke is formed. These factors lead to a different preponderance of chemicals in mainstream and sidestream smoke. For example, although twice as much nicotine is emitted in sidestream as in mainstream smoke, the ratio for benzene is approximately 10 to one; sidestream smoke is even more enriched in many other carcinogens: eg, more than 30 times as much 4-aminobiphenyl and 100 times as much *N*-nitrosodimethylamine is emitted in sidestream as in mainstream smoke. Thus, the complex chemistry of tobacco

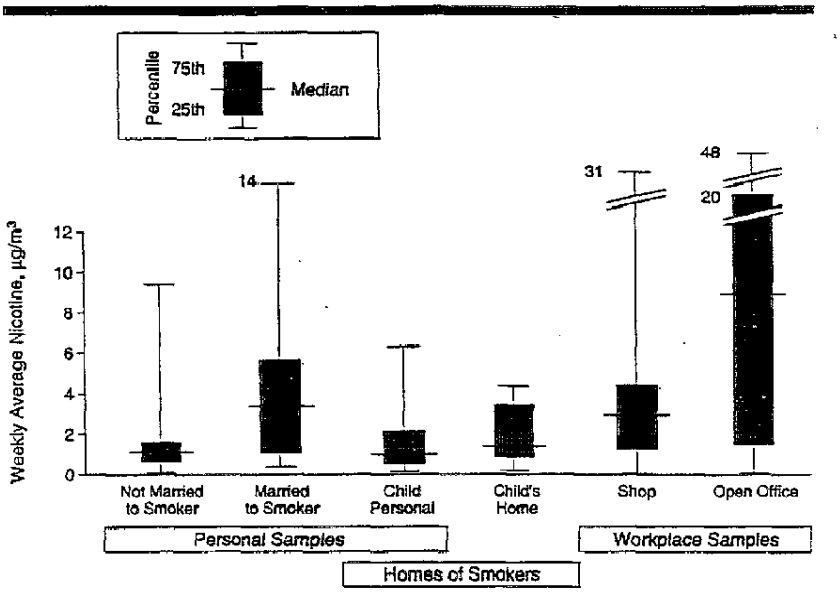

Figure 3.—Weekly average nicotine exposures in the home and at work by personal sampling (first two bars), in smokers' homes, area and personal sampling (middle two bars), and at work (this study) (last two bars).

Compound Specific Cigarette Equivalents for 8-Hour Exposures to Environmental Tobacco Smoke*

		90th Percentile of Exposure		
	Obvious-Risk	Nonoffice Workstations	Restaurant	Open Offices
Concentration of nicotine, µg/m³	2.3†	7.2‡	18§	34‖
Contaminant, cigarette equivalents				
Nicotine	0.01	0.05	0.12	0.22
Benzene¶	0.05	0.16	0.39	0.74
4-Aminobiphenyl¶	0.22	0.68	1.7	3.22
N-Nitrosodimethylamine#	0.74	2.32	5.8	11.0

*The number of "cigarette equivalents" that a passive smoker has inhaled may be calculated according to the following equations: cigarette equivalents=(amount from passive exposure/amount from smoking one cigarette); cigarette equivalent compound Y=([nicotine]×V×Y(SS)/nicotine(SS)×Y(MS)), where Y indicates mass of compound Y inhaled by passive smoker; [nicotine], concentration of nicotine; V, volume of air breathed by passive smoker (minute volume×minutes exposed); Y(SS), mass of compound Y in sidestream emissions of one cigarette; Y(MS), mass of compound Y is mainstream emissions of one cigarette; and nicotine(SS), mass of nicotine in sidestream emissions of one cigarette. Each exposure is assumed to last for 8 hours, and a ventilation rate of 20 L/min is assumed. Longer exposures will lead to proportionately higher "cigarette equivalents," as will higher breathing rates resulting from physical exertion at work.

†De manifestis level.[22] See text for definition.

‡Ninetieth percentile of samples collected from nonsmokers' nonoffice workstations at 10 Massachusetts work sites that allowed smoking.

§Ninetieth percentile of samples collected in restaurants in six cities.[31]

‖Ninetieth percentile of open office samples collected from 11 work sites that allowed smoking.

¶Human carcinogen.

#Animal carcinogen.

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smoke leads to different numbers of "cigarette equivalents" depending on which compound is examined.

Clearly, "cigarette equivalents" can be a misleading term. A recent RJ Reynolds advertisement (*New York Times*. May 23, 1994:A11) stated that nonsmokers are exposed to only slightly more than one "cigarette equivalent" a month at the workplace. More accurately, a nonsmoker gets as much nicotine in a month at work as a smoker does in smoking one cigarette. However, in that same room, at the same time, the nonsmoker is getting as much benzene as a smoker gets in smoking six cigarettes, as much 4-aminobiphenyl as if smoking 17 cigarettes, and as much *N*-nitrosodimethylamine as one who smoked 75 cigarettes.

The Table presents some calculations of cigarette equivalents for several compounds of interest. Four hypothetical exposure situations are assumed: the de manifestis risk level (2.3 $\mu g/m^3$)[22] and the 90th percentile of nonoffice workspaces (7.2 $\mu g/m^3$), open office spaces (34 $\mu g/m^3$), and restaurants (18 $\mu g/m^3$).[30] For each setting, the calculated cigarette equivalent exposure ranges more than 1000-fold, and a description of exposure in nicotine cigarette equivalents yields a fivefold to 50-fold underestimate of the exposure to some of the known carcinogens. If the compound of interest is known, the cigarette equivalents for that compound can be calculated from the concentrations of nicotine measured and the relative sidestream and mainstream emissions of that compound.[23] If the compound of interest is not known, which is most commonly the case, then any such calculations are likely to be misleading at best and should be used with extreme caution.

Conclusions

A wide range of ETS exposures exists within and among workplaces. Policies restricting or banning smoking were found to reduce occupational exposure to ETS dramatically. The concentration of nicotine depends not only on the smoking activity but also on the characteristics of the space in which the smoking occurs. The ETS does not build up as much in workspaces that are large, with high ceilings and good ventilation, as in more enclosed spaces. Despite this, ETS measurements in nonoffice or shop workspaces where smoking was allowed were generally comparable with, and often much greater than, most measurements made in the homes of smokers; 12% of the 114 samples collected at nonsmokers' shop workstations were above the significant risk level of 6.8 $\mu g/m^3$. The ETS concentrations were even higher in office spaces that allowed smoking, where more than half of the 61 samples collected at nonsmokers' desks were above the significant risk level. Society is often presented with difficult alternatives, such as choosing between exposing workers to carcinogens and losing jobs if industry decides the cost of controlling exposures is too great. Choosing to control exposure to ETS, in this context, is relatively simple: ETS is not necessary to the manufacturing process or to the maintenance of jobs.

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